Sources of Noise and Noise Sources

By G. R. JESSOP, A.M.I.E.R.E., G6JP*

IN order to make the best use of radio signals, it is necessary to amplify them to a workable level but in such a manner that the noise generated in doing so does not submerge the wanted signal. The relationship between noise and signal, commonly known as the signal-to-noise ratio is of prime importance in any receiving system, and one of the design objects is always to keep this ratio as high as possible.

When seeking to evaluate signal-to-noise ratio, it is necessary to know what are the causes of noise, and to have available a means of testing and setting up the receiving equipment for the best performance in relation to the particular function that it has to perform.

Broadly speaking, noise can be divided into two categories:

(a) External noise—including atmospherics, thermal noise from the earth, solar and cosmic noise, man-made static etc.;

(b) Internal Noise—that generated within the receiving equipment such as resistive noise, shot noise, flicker noise, partition noise, transit time and induced grid noise.

Since we can do little or nothing about externally produced noise, apart perhaps from using effective limiters to mitigate their effect, any improvement in the signal-to-noise ratio within our control relates to the performance of the receiving equipment itself and its internal noise.

The various forms of internal noise, how and why they are produced, are briefly as follows.

Resistive Noise

This type of noise is to be found in all resistors, together with the resistive elements of inductance and capacitance. The actual level of resistive noise depends on the type and construction of the resistor.

Even a so-called " ideal " resistor of the metallic type will generate noise. This noise is created by the random movement of free electrons within the molecular structure of the resistive element, and since the " activity " of these electrons is dependent on temperature, the level of noise will vary with changes in temperature.

Some qualification of the foregoing temperature *v* noise statement is however needed. Most resistors operate at a temperature in the region of 17°C or 290°K unless special cooling is undertaken. Since it is only at Absolute Zero—273°K below 0°C—that the motion of the random electrons ceases, and the resistor would become " silent ", it will be appreciated that, over the normal working temperature range, any changes in temperature will be proportionately very small when compared to the elevation above absolute zero. For this reason, the inherent noise level within average resistors does not change very appreciably over the range of temperatures encountered under normal working conditions.

Carbon resistors, which are almost universally employed in equipment, are likely to be as much as ten times more noisy than metallic types, and this fact should be borne in mind when producing items such as high gain microphone amplifiers.

As a matter of interest, specially designed resistors operated at high and/or low temperatures, are available for use as noise sources for equipment evaluation.

Shot Noise

Shot noise arises from the random emission of electrons from a hot cathode within a valve structure.

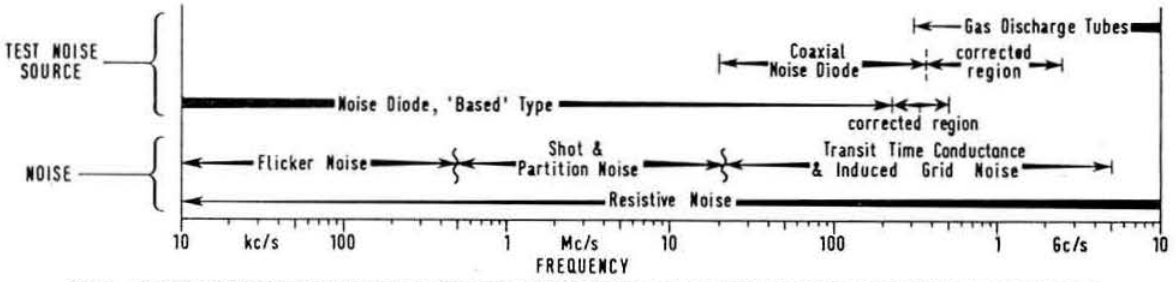

Fig. 1. Diagram indicating the frequency of various forms of noise and the standard noise sources used for test purposes.

There are two classifications of emission from the cathode or filament of a valve, one being designated " saturated emission " and the other " non-saturated emission." In the former, and considering a simple diode with a pure tungsten filament, the anode current will be directly controlled by the temperature of the filament, and when this is at its permitted maximum, the anode will " take-up " all the electrons available from the filament. There are no " spares " drifting around.

Under non-saturated emission conditions, there is much more emission available from the cathode/filament, than that which is being drawn by the anode. This gives rise to a space charge between the filament and the anode, and this has the effect of smoothing out some of the fluctuations in anode current caused by the shot effect. Most valves employed in equipment are operated under space charge conditions—i.e. non-saturated emission—and the anode current fluctuations are much less than in the case of the saturated emission diode used in noise generators.

Flicker Noise

This takes the form of large amplitude pulses, and is produced in some types of valves at low frequencies, being, generally, most troublesome in the frequency range 100 c/s-50 kc/s.

In high gain audio amplifiers, the presence of this noise form is most detrimental to satisfactory operation, and has led to the development of special " low noise " valves for this particular application. The EF86 and its associated types are examples.

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Partition Noise

In multigrid valves, the division of the total cathode current between the anode and the various other electrodes are subject to the fluctuations caused by shot effects. In turn, these additional electrodes will, by a process similar to modulation, cause increased random fluctuations in the anode current.

From this it will be appreciated that the fewer the electrodes in a valve the better, and moreover, why it is that a triode will always have a much lower noise factor than a pentode or other multi-electrode valve.

Transit Time Conductance and Induced Grid Noise

The random fluctuations in the electron stream emitted from the hot cathode—*see shot noise*—in passing through the grid structure on the way to the anode, will induce a noise voltage on to the grid from the electrostatic charge carried by the electrons themselves.

The magnitude of this will depend on frequency. At low and medium frequencies, this noise will be self-neutralized as the voltage induced by the electrons approaching the grid will be cancelled by an equal and opposite voltage induced by those receding from the grid. At higher frequencies, however, 20 Mc/s and upwards, the actual time taken by an electron to pass from cathode to anode will be an appreciable fraction of the operating cycle, the fraction increasing with frequency. This transit time, as it is known, results in a difference in phase between the electrons approaching the grid, and those receding from it. The result is that not all the induced voltage is cancelled.

As the frequency is raised, the magnitude of the current induced in the grid also rises. This approximates to a resistive thermal noise generator operating at a relatively high temperature. This effect is normally termed transit time conductance, the value of which is proportional to the square of the operating frequency.

In order to assess the merit of a valve for receiver purposes, two parameters are often quoted: (a) Equivalent Noise Resistance and (b) Noise Factor.

Equivalent Noise Resistance

This is defined as an ideal resistance which, when maintained at a normal operating temperature, would, if placed in the grid of a noiseless valve, produce anode current fluctuations equal to shot and partition noise of an actual valve of similar characteristics.

This method of assessment has been used for many years on the continent, but it is only really of value in the frequency range 50 kc/s to 20 Mc/s. It is of little or no value in equating a valve for suitability in v.h.f. or u.h.f. applications.

The equivalent noise resistance for various types of valves can be calculated as follows:

(i) *Triode* (Shot Noise only)

$$R_{eq} = \frac{2{\cdot}5}{G_m} \text{ ohms}$$

(ii) *Pentode or Tetrode* (Shot and Partition Noise only)

$$R_{eq} = \frac{I_a}{I_a + I_{g2}} \times \left(\frac{2{\cdot}5}{G_m} + \frac{20\, I_{g2}}{G_m{}^2}\right) \text{ ohms}$$

(iii) *Triode Mixer* (Shot noise only)

$$R_{eq} = \frac{4{\cdot}0}{G_c} \text{ ohms}$$

(iv) *Pentode or Multigrid Mixer* (Shot and Partition Noise only)

$$R_{eq} = \frac{I_a}{I_a + I_{g2}} \left(\frac{4{\cdot}0}{G_c} + \frac{20\, I_{g2}}{G_c{}^2}\right) \text{ ohms}$$

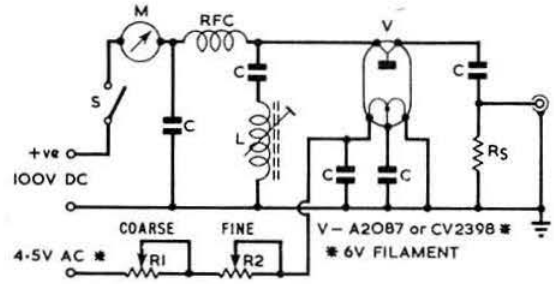

Fig. 2. A simple noise generator using a temperature limited saturated emission noise diode valve, suitable for most noise measurements above 20 Mc/s.

In the foregoing formulae, the value of I_a and I_{g2} is expressed in *amps*, while that for g_m and g_c are in *amps/volt*.

From these calculations it will be seen that the lower the equivalent noise resistance, then the better the valve. While this is true at frequencies where the induced grid noise is not troublesome, and while valves with a high g_m will produce the lowest equivalent noise resistance, this does not automatically make them the most suitable for every application.

Noise Factor

There is more or less a standard method of expressing the performance of a valve intended for service as an r.f. amplifier on frequencies above 20 Mc/s; this is quoted as its noise factor. Assuming that the first stage has adequate gain, this can also be used to state the performance of receivers and converters.

The measurement of noise factor is carried out using a diode noise source such as the A2087 whose noise performance can be calculated from

$$F = \frac{e}{2kT}\, I_d\, R_s$$

where e = the electron charge = $1{\cdot}59 \times 10^{-19}$ coulomb
k = Boltzmann's constant = $1{\cdot}372 \times 10^{-23}$ joules per °K
T = Temperature of source resistance in °K.
I_d = noise diode anode current in amperes.
R_s = Source resistance in ohms.

In cases where the normal operating temperature is of the order of 17°C—290°K—the formula can be simplified to

$F = 20\, I_d\, R_s$ as a ratio,
or $F = 10 \log (20\, I_d\, R_s)$ in decibels.

Noise diodes are available for frequencies up to about 500 Mc/s or so, but when measurements are made at or near the maximum frequency of the noise source, some precautions are necessary to avoid producing optimistic results, and corrections are often needed. For most purposes, however, the diode noise generator is an entirely reliable and stable source producing repeatable results, and when used up to

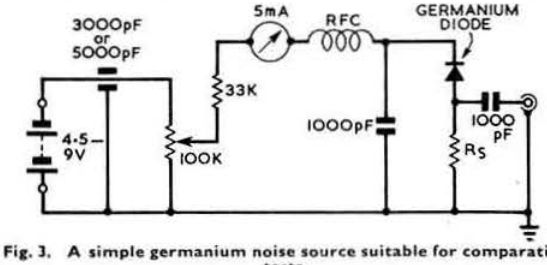

Fig. 3. A simple germanium noise source suitable for comparative tests.

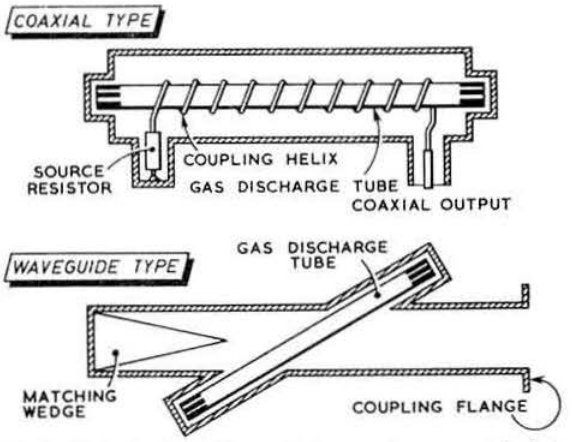

Fig. 4. Methods of coupling a discharge noise source tube into coaxial and waveguide circuits for measurements above 500 Mc/s.

about 150 Mc/s little or no correction is needed provided that a suitable diode is employed.

The circuit of a diode valve noise generator is given in Fig. 2. This will perform the tests required on most amateur equipment for frequencies above 20 Mc/s, and possesses a high degree of repeatability over long periods. It should be noted that if a CV2398 diode is used in place of the A2087, then the filament supply must be increased to 6 volts.

For comparative tests, and when repeatability over a short period is adequate, then the simpler germanium diode noise generator given in Fig. 3 will be found quite satisfactory.

Gas Discharge Tube Noise Sources

At frequencies of 500 Mc/s and above, it is usual to find that an inert gas discharge tube is employed as the noise source. Some special noise diodes however can be used up to 1000 Mc/s but corrections for transit time errors must be made, and it is for this reason that the gas discharge tube usually takes over.

In a gas discharge tube, the positive column of gas emits electromagnetic radiation, and this can be readily coupled into either a co-axial line or wave guide circuit. The usual methods are shown diagramatically in Fig. 4.

Conclusion

Although some of the noises specified above are produced by the functioning of valves themselves, it should not be thought that noise is the prerogative of the hot cathode valve alone. The transistor, while a " cold " device, can make equal, and often better, noises. Therefore any apparatus built to test valve amplifiers will be equally useful in evaluating transistor amplifier performance.

Suitable test procedures are given in detail in the *Amateur Radio Handbook*, along with further information on the subject of noise generally.

Electronics Course for Teachers

By D. Bond, BRS21555*

It has been felt for some time by the writer that in consequence of the vast strides which have taken place in the field of electronics over the last decade, there is an urgent need for science teachers to " rethink " some of their ideas of the scope of electronics and to learn something of the newer techniques of construction. Not least of all there is the need to " sell " electronics as an enrichment subject to the pupils.

With these thoughts in mind, a sub-committee of the Association for Science Education (Essex Branch), under the sponsorship of the Essex Education Committee, recently staged a four-day course at the Mid-Essex Technical College, Chelmsford. The course was very largely practical, and included instruction on soldering, and demonstrations of the use of Veroboard, Eyelet Board, etc. After lectures on the physics of the transistor, course members set to work to construct various transistor units, including multivibrators, receivers, photo-electric devices, and amplifiers. The beams of joy which spread across the faces of some of the members when these actually worked had to be seen to be believed!

The theme of " Electronics for Enrichment " was well reinforced by Ken Smith, G3JIX, who delighted everyone with a talk on his work with the Roding Boys' Club. Other lecturers included K. Bowden of the Mullard Education Service, Dr. Houghton, B. Pounder and C. T. Crellin, Science Adviser (Middlesex County Council).

Although we were very careful to avoid any suggestion that we were trying to brainwash the teachers into becoming radio amateurs, a station was set up by Jim Turner, G3AYZ, using a special call-sign G3ASE, and a total of 43 contacts was made, mostly on 80m. Few contacts were made on 20m possibly because the aerial was screened by large buildings. However, reports were RS5/6 from W2. The gear consisted of a KW2000 kindly loaned by G3ORT, a G2DAF transmitter and receiver (built by G3AMF), and a 10 watt transmitter from G3AYZ. The station was operated throughout by G3AYZ and G3EDM, ably assisted by s.w.l. Michael Marsh, A4024.

The inspiration for this Course came from an article in the November, 1962, BULLETIN describing a teachers course run at the Kent Summer School by D. J. Bradford, G3LCK, of Canterbury, to whom the writer is indebted for help and encouragement in the early stages of the planning.

The Association is greatly indebted to the following help from industry—Mullard Education Service, Philips Electrical (display of electronic kits), Erectronic Ltd. and R. Lamb Ltd. (Eyelet Board).

There is no doubt that this kind of course can have considerable impact on science teachers, and does much to encourage the enjoyment of a subject which can prove so valuable to our children in later years.

A general view of the "class" of teachers actively engaged in their separate projects.

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